North Pacific Acoustic Laboratory: Deep Water Acoustic Propagation in the Philippine Sea

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LONG-TERM GOALS

The North Pacific Acoustic Laboratory (NPAL) program is intended to improve our understanding of (i) the basic physics of low-frequency, broadband propagation in deep water, including the effects of oceanographic variability on signal stability and coherence, (ii) the structure of the ambient noise field in deep water at low frequencies, and (iii) the extent to which acoustic methods, together with other measurements and coupled with ocean modeling, can yield estimates of the time-evolving ocean state useful for acoustic predictions. The goal is to determine the fundamental limits to signal processing in deep water imposed by ocean processes, enabling advanced signal processing techniques to capitalize on the three-dimensional character of the sound and noise fields.

OBJECTIVES

A series of deep-water acoustic propagation experiments combining low-frequency, broadband sources with vertical and horizontal receiving arrays were conducted in the North Pacific Ocean during the period 1989 to 2005 as part of what is loosely referred to as the North Pacific Acoustic Laboratory (NPAL) (Worcester and Spindel, 2005). These experiments were designed to measure the spatial and temporal statistics of the fluctuations of resolved rays and normal modes. The results reflect the

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background sound-speed field, the low level of eddy variability, the small-scale sound-speed fluctuations caused by internal waves and density-compensated temperature and salinity variations (spice), and the noise sources found in the relatively benign northeast and north central Pacific Ocean.

During 2009–2011 the methods developed to study long-range, deep water broadband acoustic propagation in the North Pacific were applied to investigate deep-water acoustic propagation and ambient noise in the much more oceanographically and geologically complex northern Philippine Sea. Three experiments were conducted: (i) 2009 NPAL Pilot Study/Engineering Test (PhilSea09), (ii) 2010–2011 NPAL Philippine Sea Experiment (PhilSea10), and (iii) Ocean Bottom Seismometer Augmentation of the 2010–2011 NPAL Philippine Sea Experiment (OBSAPS).

The goals of the Philippine Sea experiments included (i) understanding the impacts of fronts, eddies, and internal tides on acoustic propagation, (ii) determining whether acoustic methods, together with other measurements and ocean modeling, can yield estimates of the time-evolving ocean state useful for making improved acoustic predictions and for understanding the local ocean dynamics, (iii) improving our understanding of the physics of scattering by internal waves and spice (density-compensated temperature and salinity variations), (iv) characterizing the depth dependence and temporal variability of the ambient noise field, and (v) understanding the relationship between the acoustic field in the water column and the seismic field in the seafloor for both ambient noise and signals.

APPROACH

The three NPAL Philippine Sea experiments are described in detail in Worcester *et al*. (2013). A brief summary follows.

PhilSea09. A short-term Pilot Study/Engineering Test was conducted in the Philippine Sea during April-May 2009. A single acoustic path, approximately corresponding to one of those to be instrumented during the 2010–2011 PhilSea10 experiment, was instrumented with a Teledyne Webb Research swept-frequency source (T1) and a prototype Distributed Vertical Line Array (DVLA) receiver (Worcester *et al*., 2009). The DVLA consisted of two 1000-m subarrays: an *axial subarray* spanning the sound-channel axis and a *deep subarray* spanning the surface conjugate depth. Each subarray contained 30 Hydrophone Modules. Both moorings remained in place for about one month, while coordinated, ship-based measurements were made. These included transmissions to the DVLA from sources suspended from shipboard and recording of the T1 and ship-suspended source transmissions by the towed Five Octave Research Array (FORA).

PhilSea10. The 2010–2011 NPAL Philippine Sea deep-water acoustic propagation experiment combined measurements of acoustic propagation and ambient noise with the use of an ocean acoustic tomography array to help characterize this oceanographically complex and highly dynamic region. A full water-column-spanning DVLA consisting of five 1000-m subarrays, with a combined total of 150 Hydrophone Modules, was deployed within an array of six broadband acoustic transceivers (T1-T6) from April 2010 until March-April 2011 (Fig. 1). All six of the moored sources were Teledyne Webb Research swept-frequency acoustic sources similar to the source deployed during PhilSea09. The DVLA recorded the transmissions from the six sources in order to study acoustic propagation and scattering. Each acoustic transceiver also recorded the transmissions from the other transceivers, forming a six-element ocean acoustic tomography array with a radius of approximately 330 km. The tomographic measurements, when combined with satellite, glider, and other in situ measurements and

with ocean models, will provide an eddy-resolving, 4-D sound-speed field for use in making acoustic predictions.

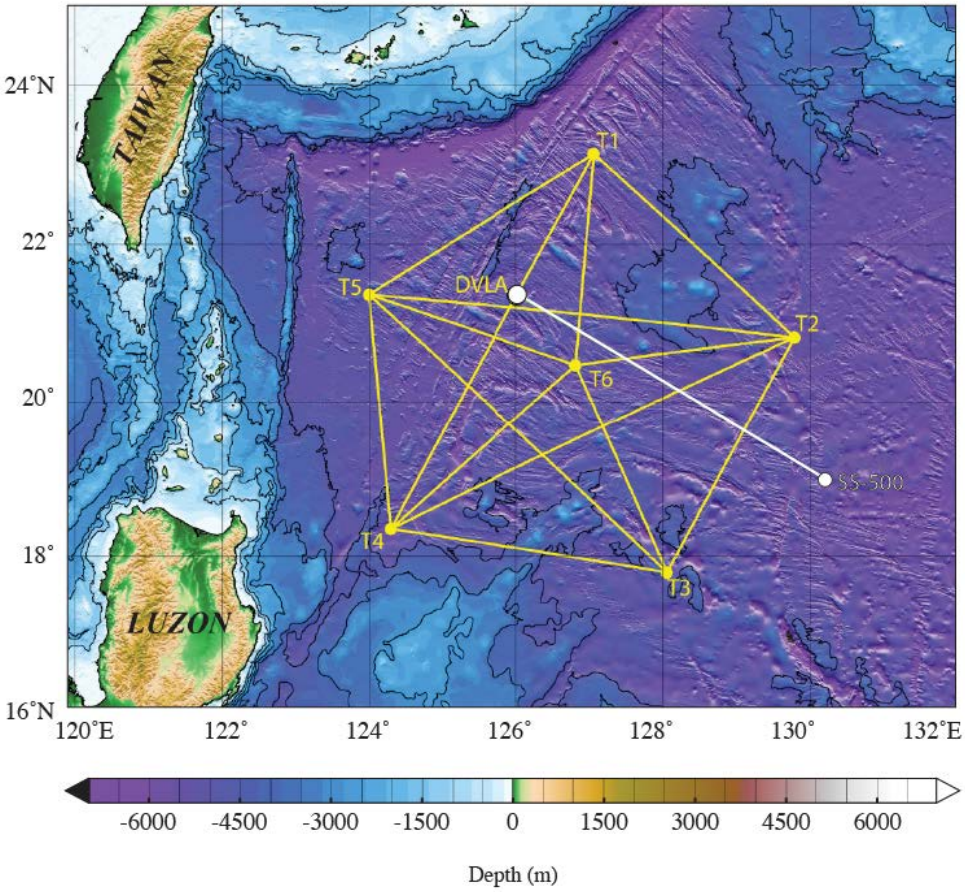

Figure 1. Geometry of the PhilSea10 experiment. A Distributed Vertical Line Array receiver was moored at DVLA. Broadband acoustic transceivers were moored at T1-T6. Ship-suspended sources transmitted to the DVLA from ship station SS-500. (Reproduced from Worcester et al., 2013.)

During May 2010 MP-200 Multiport and HX-554 sources suspended from shipboard at ship station SS-500 transmitted to the DVLA (Andrew *et al*., 2010). During July 2010 a J15-3 source suspended from shipboard transmitted to the DVLA at fixed locations approximately one-half and one convergence zone from the DVLA and during a number of tows.

Four acoustic Seagliders were deployed during November 2010 in the vicinity of the PhilSea10 moored array (Howe *et al*., 2011; Van Uffelen *et al*., 2013). The gliders measured temperature and salinity in the upper 1000 m of the ocean between the moorings and recorded the transmissions from the moored acoustic sources. A major objective was to determine whether, given the joint nature of the combined navigation/tomography problem, it is possible to use Seagliders equipped with an Acoustic Recorder System (ARS) as mobile nodes in a tomographic array, thereby enhancing the resolution of the tomographic system.

OBSAPS. A near-seafloor, 1000-m long O-DVLA (OBSAPS-DVLA), with a total of 15 Hydrophone Modules, and an array of six ocean bottom seismometers (OBS) were deployed in the Philippine Sea during April-May 2011, immediately following recovery of the PhilSea10 moorings, to study the relationship between the acoustic field in the water column and the seismic field in the seafloor for

both ambient noise and signals transmitted by a ship-suspended J15-3 source (Stephen *et al*., 2011). (One of the OBS did not return data.) The O-DVLA and OBS remained in place for approximately one month.

WORK COMPLETED

Analysis. Analyses of the PhilSea09, PhilSea10, and OBSAPS data sets continued throughout FY13. Manuscripts were prepared for publication in a special issue of the *Journal of the Acoustical Society of America* entitled "Deep-water Ocean Acoustics," as described below.

D-STAR2 Development. During FY13 we continued a design effort to develop a simpler, smaller, and cheaper DVLA controller employing the Symmetricom Chip-scale Atomic Clock (CSAC) that is now available. The CSAC eliminates the need for the complex dual-oscillator system currently employed in the D-STAR. The existing system has a precise, but high power, rubidium oscillator that is turned on once a day to check the frequency of a less precise, but low power, Q-Tech Microcomputer Compensated Crystal Oscillator (MCXO). Our tests have shown that that CSAC meets its specifications and will provide adequate timing precision without the need for a two-oscillator system.

RESULTS

The results to date from the NPAL Philippine Sea experiments are included in a special issue of the *Journal of the Acoustical Society of America* entitled "Deep-water Ocean Acoustics" scheduled for publication in October 2013. P. Worcester (SIO) and J. Colosi (NPS) are the Guest Editors (Colosi and Worcester, 2013). The NPAL-related papers in the special issue are Chandrayadula *et al*., 2013a, b; Colosi, 2013; Colosi *et al*., 2013a,b; Dzieciuch *et al*., 2013; Farrell and Munk, 2013; Freeman *et al*., 2013; Heaney *et al*., 2013; Powell *et al*., 2013; Skarsoulis *et al*., 2013; Stephen *et al*., 2013; Udovydchenkov *et al*., 2013; Van Uffelen *et al*., 2013; White *et al*., 2013; and Worcester *et al*., 2013. These papers include results from the 2004–2005 NPAL experiment in the central North Pacific, in addition to results from the NPAL Philippine Sea experiments.

IMPACT/APPLICATIONS

This research has the potential to affect the design of deep-water acoustic systems, whether for sonar, acoustic communications, acoustic navigation, or acoustic remote sensing of the ocean interior.

RELATED PROJECTS

A large number of investigators have been involved in research related to the NPAL project during this period, including R. Andrew (APL-UW), A. Baggeroer (MIT), M. Brown (UMiami), R. Campbell (OASIS), T. Chandrayadula (NPS), J. Colosi (NPS), G. D'Spain (MPL-SIO), B. Dushaw (APL-UW), K. Heaney (OASIS), F. Henyey (APL-UW), B. Howe (Univ. Hawaii), J. Mercer (APL-UW), V. Ostachev (NOAA/ETL), B. Powell (Univ. Hawaii), S. Ramp (SOS), R. Stephen (WHOI), I. Udovydchenkov (WHOI), L. Van Uffelen (SIO), A. Voronovich (NOAA/ETL), and K. Wage (George Mason Univ.).

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HONORS/AWARDS/PRIZES

W. H. Munk: Japanese Drilling Ship *Chikyu* Science Room renamed *"Walter Munk Library"* by JAMSTEC President Asahiko Taira while onboard for an honorary visit — helicoptered 85 km out to sea (November 5, 2012)

W. H. Munk: Award for Distinguished Contributions to Wave Analysis and Forecasting (Philadelphia, PA) by Surfline and Buoyweather (April 24, 2013)

W. H. Munk: "FULL PERFORMANCE BY MAN" Award Universidad Autonoma de Baja California, Facultad de Ciencias Marinas (Ensenada, Mexico) XXI Student Congress (May 14–16, 2013)

W. H. Munk: Ocean Conservation Award by Dr. Jerry Schubel, President & CEO of the Aquarium of the Pacific (Long Beach, CA) Keynote Speaker (June 15, 2013)

W. H. Munk: Honor for Contributions to Naval Oceanography United States Navy, Fleet Weather Center (San Diego, CA)

Keynote Speaker: *"Where the Swell Begins"* (July 26, 2013)

W. H. Munk: ICMDIS Award for Pioneering Contributions to Ocean Science (Lucca, Italy) by Frederico de Strobel (September 22–25, 2013)